Application of rarefied gas dynamics for design of the ITER optical diagnostics

64th IUVSTA Workshop, May 16-19th 2011  |  V. Kotov, D. Reiter, IEK-4 - Plasma Physics
Mirrors in ITER

- Optical diagnostics bring most of information about plasma

- Mirrors redirect light to the protected instruments
- First mirror faces the plasma directly
- Degradation of reflectivity due to incident particles

the picture is a courtesy of ITER www.iter.org
Degradation of the mirrors

- Protected in the diagnostic ducts: no direct ion fluxes
- Fast atoms (D, T, He): erosion
- Impurities (Be, C, Fe, W etc): formation of deposits
- Flux to the mirror < aperture flux
- How effective is the protection?

- Free molecular flow approximation (MFP > 3 m, size ~ 1 m) ⇒ straightforward numerical modelling
Special feature 1: non-thermal incoming particles

3D distribution function $f(E, \theta, \phi)$. Neutral particles come:

- From the plasma facing components
- From plasma: charge-exchange and elastic collisions

- “Reflection“ from $\sim$keV plasma: high-energetic tail of D, T
- Distribution of sources: grazing incidence prevails
Special feature 2: particle-surface interaction

- Reflection coefficients $R(E, \theta; E’, \theta’)$ for fast, $>10$ eV, particles (D, T, He):
  - Binary collisions with lattice atoms
  - TRIM code, W. Eckstein, IPP Garching
- Reflection coefficients of impurities (Be, C etc.):
  - Empiric, molecular-dynamics

- Important process: sputtering of deposited films from the duct wall
- Caveat: the data on impurity reflection and the sputtering of deposits are incomplete and uncertain
- Parametric studies and worst cases
The numerical tool: EIRENE

\[
\frac{\partial f(r, v, t)}{\partial t} + v \cdot \nabla_r f(r, v, t) = Q(r, v, i, t) + \\
+ \int \int \int \sigma(v', V'; v, V)|v' - V'|f(v')f_b(V')dv'dV'dV - \\
- f_b(V) \int \int \int \sigma(v, V; v', V')|v - V|f(v)dvdV'dV'
\]

- Linear Monte-Carlo particle transport code
  - Fixed background for test particles
- Primary application: interaction of magnetized plasma with rarefied neutral gas
  - Models for elementary processes, particle-surface interaction
- Arbitrary 3D geometry, MPI-parallelized
- Widely used in magnetic fusion community
- Developed at FZJ by D. Reiter et al., see [www.eirene.de](http://www.eirene.de)
The results of parametric studies

- An example: core-CXRS diagnostic
- ANSYS-generated grid for CAD geometry

- Experimentally found limits for erosion can be reached after $>10000$ ITER discharges. Good :-)
- ... for deposition: after 1-1000 discharges. Too bad :-(
- Impurity flux attenuation by a factor $\sim 100$: factor $>10000$ is desirable
Protection by baffles

Example:
- Impurity reflection coefficient $R_N = 0.1$
- Enhanced re-erosion

Attenuation factors ($L/D=20$):
- W/o baffles: $<1500$
- With baffles: $<20000$ (!)

But this is not a universal solution:
- Relies on $R_N < 1$, formation of molecules: $R_N \to 1$
- Geometry is not suitable for all diagnostics

**Protection by gas puff as an option ???**
- Possibly small flux: to minimize disturbance of plasma!
Summary

- Life-time and performance of the ITER optical diagnostics is limited by the degradation of mirrors
- Protecting effect of the diagnostic ducts has to be estimated
- Free-molecular flow problem with two special features:
  - Non-thermal sources of test particles
  - Complex particle-surface interaction
- The 3D test particle Monte-Carlo code EIRENE is applied
- Analysis shows that erosion can be effectively reduced
- But reduction of deposition could be insufficient
- Protection by gas puff (transition flow!) may be an option

This work has been done in frame of the ITER Service Contract C4T/09/71/OLT CHD/DIAGNOSTIC